Quarterly Report for January - March, 1996
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Abstract

The algorithm-development activities at USF during the first three months of 1996 have concentrated on field data collection and theoretical modeling. One bio-optics experiment was conducted during an AVIRIS overflight in the Florida Keys area. Two papers were published. Two papers were submitted for publishing.

Tasks Accomplished:

1. Remote sensing reflectance, irradiance from Licor, and Reagan sun-photometric data were collected during an AVIRIS overflight (March 23) campaign near the Florida Keys from March 12 - March 26.

2. A paper titled "Estimating primary production at depth from remote sensing" by Lee at el. has been published in Applied Optics.

Using a common primary production model, and identical photosynthetic parameters, four different methods were used to calculate quanta (*Q*) and primary production (*P*) at depth for a study of high-latitude, North Atlantic waters. The differences among the 4 methods relate to the use of pigment information in the upper water column. Methods 1 and 2 use pigment biomass (*B*) as an input, and a subtropical, empirical relationship between $K_d(\lambda)$ (diffuse attenuation coefficient) and *B* to estimate *Q* at depth. Method 1 uses measured *B*, but Method 2 uses CZCS-derived *B* (subtropical) as inputs. Methods 3 and 4 both use phytoplankton absorption spectra ($a_\phi(\lambda)$) data that were calculated remotely instead of *B* as input Method 3, however, use $a_\phi(\lambda)$ and $K_d(\lambda)$

values empirically derived from remote-sensing, while Method 4 use analytically derived $a_\phi(\lambda)$ and $a(\lambda)$ (total absorption coefficient) spectra based on hyperspectral remote measurements.

In comparing calculated to measured values of $Q(z)$ and $P(z)$, Method 4 provided the closest results [$P(z)$: $r^2 = 0.95$ (n = 24); and $Q(z)$: $r^2 = 0.92$ (n = 11)]. Method 1 gave the worst results [$P(z)$: $r^2 = 0.56$; and $Q(z)$: $r^2 = 0.81$]. These results indicate that the analytically derived $a_\phi(\lambda)$ and $a(\lambda)$ can be applied to accurately estimate $P(z)$ based on ocean-color remote sensing. Curiously, application to subarctic waters of algorithms for B and K_d, both of which were empirically developed using subtropical and summer temperate data sets, apparently compensate to some extent for effects due to their implicit dependence on pigment-specific absorption coefficients (a_ϕ^*). Clearly using incorrect specific absorption coefficients(subtropical) for both the B and K_d algorithm is better than using measured B(subarctic) with a subtropically "tuned" K_d algorithm (compare Methods 1 & 2). Since remote estimates of B depend on a_ϕ^* and a_ϕ^* varies temporally and spatially, a method independent of B was sought. By rearranging the CZCS algorithm and the primary production expressions, using a_ϕ instead of B as an input to the P expression, and relating the CZCS algorithm to a_ϕ instead of B, improved results for estimating P from remotely sensed data were derived for use with CZCS class sensors. Most importantly, there is no dependence with this method on an accurate estimations of pigment-specific absorption coefficients (a_ϕ^*) for application of the absorption-based methods (Methods 3 and 4).

3. A paper titled "Method to derive ocean absorption coefficients from remote-sensing reflectance" by Lee at el. has been published in Applied Optics.

A method to analytically derive in-water absorption coefficients from total remote-sensing reflectance (ratio of the upwelling radiance to downwelling irradiance above the surface) is presented. For measurements made in the Gulf of Mexico and Monterey Bay, with concentrations of [*chl a*] ranging from 0.07 to 50 mg/m^3, comparisons are made for the total absorption coefficients derived using the suggested method and those derived using diffuse attenuation coefficients. For these coastal to open ocean waters, including regions of upwelling and the Loop Current, the results are as follows: at 440 nm the root-mean-square difference between the two is 13.0% ($r^2 = 0.96$) for total absorption coefficients ranging from 0.02 to 2.0 m^{-1}; at 488 nm the difference is 14.5% ($r^2 = 0.97$); and at 550 nm the difference is 13.6% ($r^2 = 0.96$). The results indicate that the method presented works very well for retrieving in-water absorption coefficients exclusively from remotely measured signals, and that this method has a wide range of potential applications in oceanic remote sensing. The absorption coefficient can be used to estimate the light field at depth and the absorption of photons by phytoplankton (e.g. Section 3).

4. Newly revised versions of chlorophyll a, IPAR, and clear water epsilon software packages have been delivered to the MODIS ocean team to be merged into the MODIS Beta delivery package.

5. A paper titled "SeaWiFS Algorithm for Chlorophyll *a* and Colored Dissolved Organic Matter in Subtropical Environments" by Kendall L. Carder, Steven K. Hawes, and Zhongping Lee has been submitted to Applied Optics for publication.

Semi-analytical algorithms for phytoplankton and gelbstoff absorption and for chlorophyll *a* concentration are presented for use with the SeaWiFS sensor planned for launch on the SeaStar spacecraft in 1996. With slight modifications for spectral differences, the algorithms can be used with the Japanese Ocean Color and Temperature Scanner planned for launch by NASDA on the ADEOS satellite in 1996 and the Moderate Resolution Imaging Spectrometer planned for launch by NASA on EOS-1 in 1998. The approach is to separate absorption by gelbstoff and detritus from that by phytoplankton using the 412, 443, and 555 nm spectral bands. For waters with chlorophyll *a* concentrations of more than about 5 mg m^{-3}, the algorithm saturates and switches to an empirical version relying on the 490-to-555 nm band ratio. In non-upwelling tropical and subtropical waters and summer temperate waters, the algorithm predicts phytoplankton absorption and chlorophyll *a* concentration with root-mean-square errors less than 32%. Waters tested are from the Arabian Sea, the North Pacific, the North Atlantic, and the Gulf of Mexico, with chlorophyll *a* concentrations ranging from 0.05 to 40 mg m^{-3}. The algorithm underestimates chlorophyll *a* concentration by about a factor of two for spring bloom and upwelling sites, and a similar error is expected for high-latitude waters. Accuracies for such sites can be improved simply by using parameters for phytoplankton absorption characterization consistent with the site and season.

6. A paper titled "Pigment packaging and chlorophyll a-specific absorption in high-light oceanic waters" by Bissett at el. was revised and resubmitted to Limnology and Oceanography for publishing.

The absorption of light by particles at a single wavelength, $a_{\phi}(\lambda)$, is reduced with increased packaging of the light absorption material within these particles. This reduction can be described by the parameter Q^*a:

$$Q_a^*(\lambda) = \frac{a_\phi(\lambda)}{a_{sol}(\lambda)} = \frac{a_\phi(\lambda)}{S \cdot a_{om}(\lambda)}$$

where $a_{sol}(\lambda)$ is the theoretical maximum light absorption of the cellular material, a_{om}, in a completely dissolved state(solution). In practice, the estimations $a_{sol}(\lambda)$ for living phytoplankton are hampered by the process of removing the light absorptive material (pigments) from the organic matrix of the cell. The estimations of $a_{sol}(\lambda)$ can be further hampered by the destruction of the pigment-protein complexes when an organic solvent is used to strip the pigment from the cell. What is actually being measured by any of the current methods trying to determine $a_{sol}(\lambda)$ is $a_{om}(\lambda)$, i.e. the absorption of light by the pigment material in the organic medium of the experiment (methanol, acetone, Triton-X, etc.) The solvation factor, S, in the above equation is the ratio of the true $a_{sol}(\lambda)$ to the measured $a_{om}(\lambda)$.

We have developed an internally consistent measure of $a_\phi(\lambda)$, $a_{om}(\lambda)$, chlorophyll *a* concentration, and pheopigment concentration to determine the value of $Q^*a \cdot S$. This relationship is used to determine a functional relationship for chlorophyll *a* absorption for high-light-adapted, natural phytoplankton populations in optically clear waters. The packaging effect in these waters is negligible at the red end of the spectrum. Exclusion of the weight-specific absorption of pheopigments and the assumption of a zero $a_\phi(\lambda)$ at a zero pigment (chlorophyll *a* + pheopigment) concentration produces a misleading chlorophyll *a*-specific absorption and a false determination of pigment packaging. An algorithm is developed for predicting chlorophyll *a* concentration from $a_{ph}(675)$.

PUBLICATIONS

Carder, K.L., S. K. Hawes, and Z.P. Lee, SeaWiFS Algorithm for Chlorophyll *a* and Colored Dissolved Organic Matter in Subtropical Environments (submitted to J.G.R.).

Bissett, W.P., J. Patch, K.L. Carder, and Z.P. Lee. Pigment packaging and chlorophyll a-specific absorption in high-light oceanic waters (resubmitted to Limnology and Oceanography).

Lee, Z.P., K.L. Carder, J. Marra, R.G. Steward, M.J. Perry, 1996. Estimating primary production at depth from remote sensing, Applied Optics, 35(3):463-474 .

Lee, Z.P. K.L. Carder, T.G. Peacock, C.O. Davis, and J.L. Mueller, 1996. Method to derive ocean absorption coefficients from remote sensing reflectance, Applied Optics, 35(3):453-462.

Anticipated Activities:

1. A Bering Sea cruise accompanied by a NOAA P3 airplane overflight (scheduled April 23 - May 10) will be performed on April 17 - April 29.

2. The relationships between temperature anomalies and the packaging effect and nutrients will be explored in order to reduce uncertainty in the chlorophyll algorithm.

3. Identifying AVIRIS images containing well defined clouds and shadows using machine learning methods(neural networks) before the images have been calibrated and corrected for atmospheric effects will be attempted.

4. Two papers are under preparation: a. "Removal of reflected sky-light and retrieval of in-water inherent optical properties using water remote-sensing reflectance". And b. "Polarization of remote-sensing reflectance measured at 90 degrees to the solar plane".

5. The specifications of new procurements for a SGI workstation (~ $30,000.) and a spectrophotometer (~ $ 24,000.) will be investigated.